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MELT QUALITY INVESTIGATION FOR HIGH INTEGRITY ALUMINIUM CASTINGS

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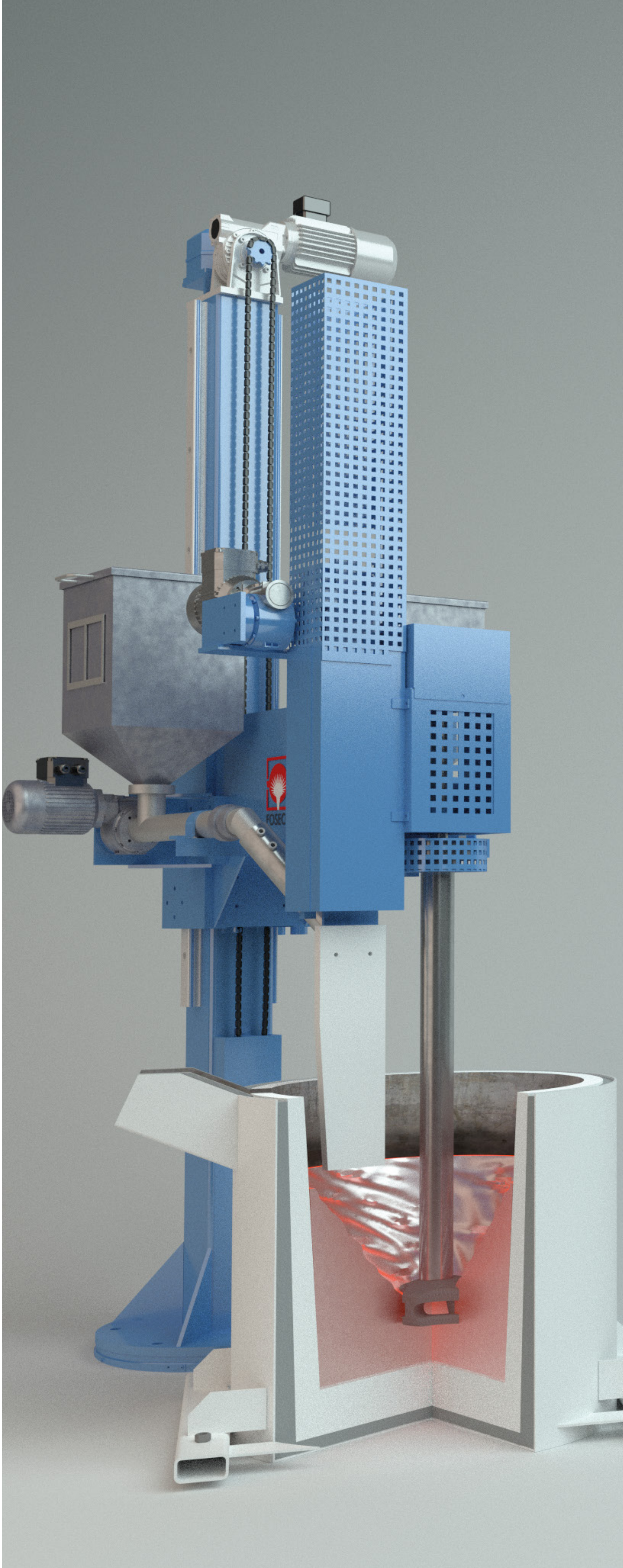
Critical metal treatment practice and quality analysis for aluminium foundries

This paper will review some of the latest benefits observed with the MTS 1500 process in terms of improving melt cleanliness when making Aluminium pistons, low-pressure wheels or melting Aluminium chips.

Some MTS case studies will focus on HPDC which is becoming the largest aluminium process driven by e-mobility.

The use of VMET (Melt Quality Assessment) has enabled us to quantify the level of melt quality improvement that is generated by the MTS 1500 Process.



INTRODUCTION

Metal treatment is a critical part of the foundry process, which often has a significant impact on casting quality [1] [2], reject rates and costs.

Hydrogen gas porosity is one of the primary concerns in Aluminium foundries [3].

But oxide removal also referred to as "melt cleaning" is becoming an increasingly important step which significantly impacts the casting's mechanical properties.

Existing cleaning practice often consists of hand fluxing or rotary degassing flux injection, but both have important restrictions or limitations.

Hand fluxing can be unreliable since it is operator dependant. Variations in addition rates, treatment times can cause major differences in efficiency and melt quality when cleaning, grain refining or doing sodium modification. This is especially true in High Pressure Die casting (HPDC) where the number of ladles or furnaces treated can exceed 100 per day.

Rotary degassing flux injection has improved some of these issues by reducing the variability due to the human factor. Unfortunately, the injection of flux through a rotating shaft requires special precautions to prevent blockages. These blockage issues will cause high maintenance and limit the injection rate of the flux thus reducing productivity.

As a solution to these issues, Foseco developed the MTS 1500[4], a robust blockage-free and reliable system to achieve multiple functions in a foundry including:

- Faster degassing using more efficient XSR / FDR rotor designs
- Cheaper cleaning & drossing especially in high-pressure die-casting
- Constant and repeatable sodium modification [5] [6]
- Cost efficient Ti-B grain refinement in gravity and wheels
- Cost saving for drossing in Aluminium HPDC
- Oxide removal in Aluminium HPDC, pistons, wheels and chip melting.

IMPROVED GRAIN REFINING IN LPDC WHEELS USING A NOVEL FLUX GRAIN REFINER

Aluminium wheels are one of the most important automotive castings made (mostly) using the Low-pressure diecasting process. As OEM wheels are considered safety components, it is critical for wheel castings to:

- be exempt of gas and shrinkage porosity
- be free of oxides and inclusions
- have a very fine microstructure which will ensure adequate mechanical properties

Grain refining [7] is one of the critical steps which most foundries achieve by adding Ti-B rod master alloy. The typical addition rate is usually around 0.1%.

Table 1 details the key process parameters used in an Asian LPDC wheel foundry where A356 alloy is being treated in 700 Kg transfer ladle prior to transfer into the low-pressure furnaces.

Alloy A356.2	Ti-B traditional process	COVERAL* MTS 1582
Ladle Size	700 Kg	700 Kg
Ti-B Flux Quantity	-	310 g
Master alloy Ti-B rod	500 g	-
Degassing Time	9 min	9 min

Table 1. Key process parameters used in an Asian LPDC wheel foundry

This wheel foundry is using 500 g of Ti-B rod master alloy in their traditional process in order to achieve the required mechanical properties. The newly introduced Flux Grain refiner (COVERAL* MTS 1582)[7] was able to achieve similar quality levels with only 310 g of flux addition.

Table 2 compares the degassing efficiency and titanium levels obtained with Ti-B master alloy and the novel grain refiner, COVERAL MTS 1582.

Alloy A356.2	Ti-B traditional process	COVERAL MTS 1582	Remarks
RPT Density @ 80mbar	2.65	2.65	Identical
Chemical Analysis	Ti: 0.114%	Ti: 0.114%	Same level
DAS in spoke section	45.88 µm	47.21 µm	Spoke section (Hot area)
DAS in rim section	26.09 µm	27.26 µm	Rim section (Cold area)

Table 2. Degassing efficiency and titanium level comparison

Furthermore, to compare both grain refining processes, the foundry took samples from wheels in order to measure UTS and Elongation.

Table 3 shows a clear improvement of the mechanical properties despite addition of a smaller amount of the novel COVERAL MTS 1582 grain refiner.

Properties in Wheel Hub	Ti-B traditional process	COVERAL MTS 1582
Yield Strength (N/mm^2)	208.1	213.5
Tensile Strength (N/mm^2)	276.0	286.7
Elongation (%)	6.8	8.0

Table 3. Improvement in mechanical properties

Figure 1 shows some micrography pictures taken from the wheel spoke which was treated with the novel COVERAL MTS 1582 grain refiner. [7]

We can see that the structure is very fine and homogeneous, which is suitable for modern OEM wheels.

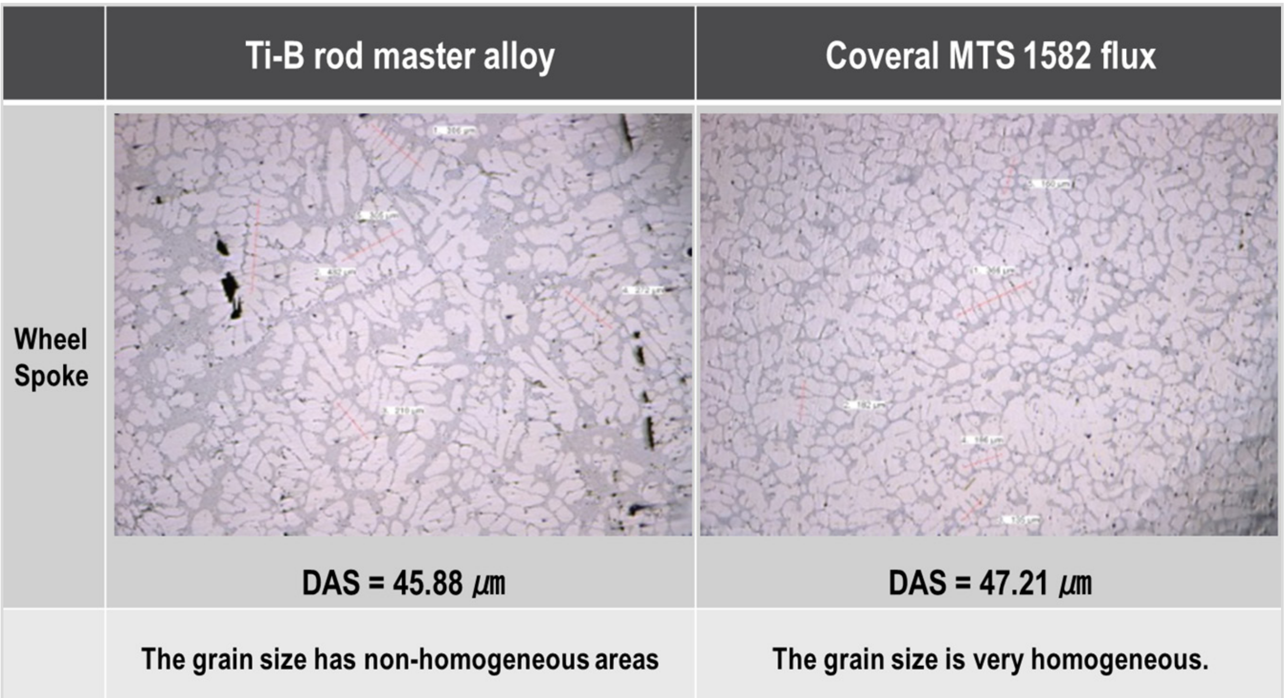


Figure 1. Micrography comparison from wheel spoke

COST SAVING IN HPDC LADLE DROSSING USING MTS 1500 PROCESS

Drossing is a key part of ladle treatment in Aluminium foundries. Globally, more than 50% of all aluminium castings are now made using the High-Pressure diecasting process.

Metal treatment is usually carried out in transfer ladles using simple degassers for 3 – 5 min.

The purpose is not to degas the melt but to remove unwanted oxides and inclusions which will float up into the dross. These oxide films can lead to defects and casting failures.

HPDC creates huge amounts of aluminium dross which can be very rich in metallic Al droplets trapped within the dross.

Figure 2 shows the dross that was collected and sampled in a very large HPDC foundry making automotive castings. The standard dross is wet and heavy with trapped Aluminium.

While the dross collected after MTS 1500 is much lighter and poor in Aluminium. Dross samples were sent to our EN R&D laboratory which analysed residual Al metal in the dross using a salt melting technique which is common in the industry.

Table 4 shows the process comparisons between the foundry's current practice and our MTS 1500. It was found that this foundry can save up to 130 Tonnes of aluminium / year which represents an annual saving of at least USD 250 K. This foundry invested into 2 MTS 1500 units type Rotostativ in 2019. Additional units are being considered for the future.

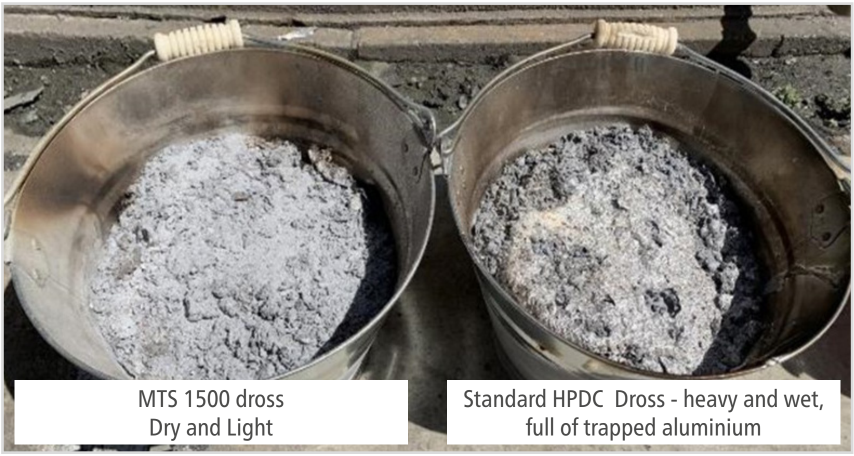


Figure 2. Dross that was collected and sampled in a very large HPDC foundry making automotive castings

Automotive HPDC foundry	Standard HPDC process	New MTS 1500 process
Ladle capacity (Kg)	1400	1400
Collected dross quantity (Kg)	4.7	3.5
Aluminium content (%)	86.4%	43.6%
Aluminium lost in dross (Kg)	4.06	1.53
Aluminium saved / ladle (Kg)	-	2.53
Number ladles / day	180	180
Number ladles / year	54 000	54 000
Aluminium saved / year (Kg)	-	136 879
Flux cost / year (USD)	-	$47 250
Foundry savings @ LME price	-	$253 884

Table 4. Process cost comparison in HPDC

VMET [8] ASSESSMENT IN EUROPEAN WHEEL FOUNDRY

In the Last 20 years, aluminium wheels have become the standard for car makers around the world.

The preferred manufacturing route for OEM wheels is Low Pressure Diecasting (LPDC) using A356 alloy which can meet the required mechanical specifications after T6 heat treatment.

But adequate melt quality is a key requirement which can often be tarnished by the excessive presence of porosity, shrinkage, or oxides.

Some European wheel foundries asked us to conduct a melt quality audit using VMET to assess the quality of their melts. Samples were taken from their transfer ladles prior to (as melted) and after various treatment processes.

Table 5 summarizes the VMET findings and clearly shows significant quality improvements as:

- The total number of features is reduced by 93% after MTS 1500 (from 917 to 62).
- Total aluminium oxides is reduced by 93% after MTS 1500 (from 225 to 16)
- Other inclusions are reduced by 91% after MTS 1500 (from 92 to 8)
- More importantly, all the worrying features > 15 microns are reduced by 98% (from 137 to 3).

Foundry	VMET Features explanation	European Aluminium Wheel foundry		
Alloy		Al-Si7%-Mg0,3% (A356)		
Sample Description		A356 alloy as melted	After 10 min Rotary degassing (FDU)	After 10 min MTS 1500 treatment
Total Features	Total # of defects porosity & inclusions	917	377	62
Features by Nature & Chemistry				
Pore	Gas and shrinkage porosity	600	234	38
Aluminium Oxides (Al_2O_3)	Aluminium Oxide & Mg Spinels	225	98	16
Other inclusions	Other inclusions (carbides, refractory, ..	92	45	8
Features and inclusions By Size				
0.50 – 15.0 µm	Little significance in castings	780	368	59
Σ all features > 15.0 µm	Defects are a concern in castings	137	9	3

Table 5. VMET analysis in a European wheel foundry

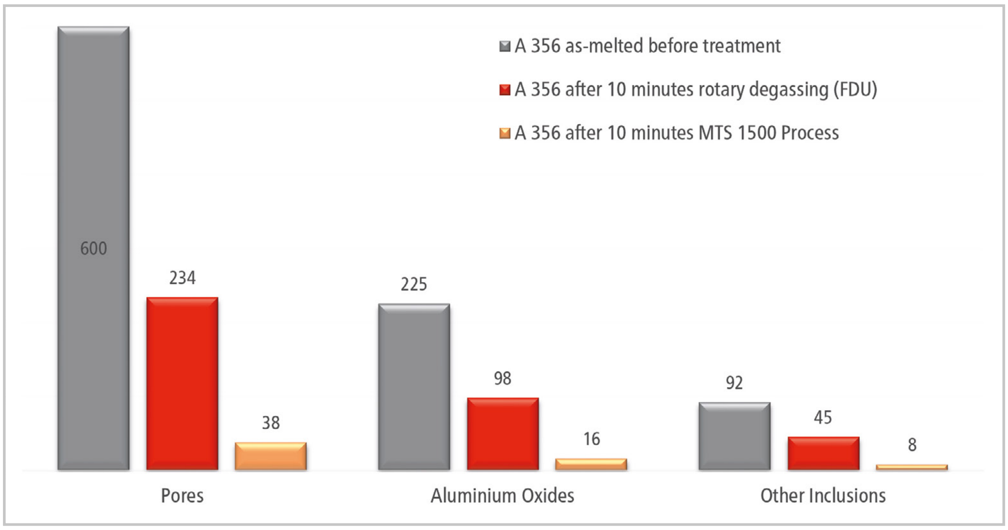


Figure 3. VMET in wheel foundry

VMET analysis is showing that MTS 1500 has a significant impact on melt quality in wheel foundries by reducing unwanted defects like porosity, oxides and other non-metallic inclusions as shown in Figure 3. This trend has led to a strong development of MTS 1500 use in wheel foundries around the world.

VMET [8] ASSESSMENT OF INTERMETALLIC INCLUSIONS IN HPDC FOUNDRY

More than 50% of all Aluminium castings are now made using the High-Pressure diecasting process in the world.

Metal is usually transferred from the melting to the casting furnaces using transfer ladles with capacities ranging from 300 Kg up to 1500 Kg.

During this melt transfer, some basic metal treatment is performed using rotary degassers for 3 – 5 min.

The purpose is not to remove hydrogen but unwanted oxide films and inclusions that can lead to defects and casting failures.

Figure 4 shows a typical transfer ladle undergoing metal treatment using MTS 1500 Rotostativ with following attributes:

- Casting: Automotive transmission
- Alloy: ADC12 secondary ingot
- Ladle capacity: 1400 Kg
- Flux addition: 0.03% COVERAL MTS 1565
- Treatment time: 3 min only
- Rotor XSR 220.70 + DSK 75/800.70

This automotive foundry asked to evaluate their melt treatment practice using VMET on several transfer ladles prior to filling the casting furnace. Table 6 shows the VMET results before and after MTS 1500 treatment in the transfer ladle.

Figure 4. MTS treatment in HPDC foundry

In the case of both ladles, the VMET analysis found:

- an overall reduction of the total number of features, oxides and inclusions.
- the oxides and inclusions larger than 15 µm were completely eliminated
- the Fe-linked intermetallic components that can be present in HPDC alloys were reduced significantly.

VMET shows a clear impact of MTS 1500 process on melt quality in HPDC.

Ladle	**Ladle 1**		**Ladle 2**		**Comments/Explanation**
Sample from ladle	Before	After	Before	After	
RPT density (g/cc)	2.27	2.62	2.25	2.61	Fit for purpose degassing improvement
Total Features	1973	296	243	70	Overall reduction of total features
Total aluminium oxides	1683	253	205	63	Overall reduction of oxide presence
0.5 - 15 µm	1682	253	205	63	Little significance in casting
> 15 µm	1	0	0	0	Reduction of oxides
Total other inclusions	290	43	184	7	Overall reduction of inclusions
0.5 - 15 µm	285	43	183	7	Little significance in castings
> 15 µm	5	0	1	0	Reduction of inclusions

Table 6. VMET results before and after MTS 1500 treatment

VMET [8] ASSESSMENT OF MAGNESIUM OXIDES IN A PISTON FOUNDRY

Aluminium Pistons have become the norm in the automotive industry due to their relative strength vs light weight. But to achieve such performance, pistons must be free of porosity, oxides & inclusions as well as unwanted alkali elements like Na or Ca which at levels > 5 ppm will affect mechanical properties. One additional issue are the magnesium oxides forming in the melt due to the high Mg content of eutectic piston alloys like ACA8-336-LM13.

Hence, particular care is given to metal treatment which includes the use of rotary degassers with injection or addition of various fluxes or gases designed to remove such impurities. Chlorine gas (Cl_2) or chlorine releasing fluxes (C_2Cl_6) are still used in some parts of the world, but they are no longer perceived as the most environmentally friendly technology. As can be seen below, there are often strong chlorine emissions linked with the use of such toxic additives.

- $C_2Cl_6 + [Na] \rightarrow NaCl + Cl_2$ gas
- $C_2Cl_6 + [Ca] \rightarrow CaCl_2 + Cl_2$ gas

Due to environmental pressure, a new MTS 1500 technology shown in figure 5 has developed in Aluminium pistons foundries which combines the use of Rotary degassing using inert gases (Ar, N_2) and several types of fluxes which have dual functions:

1. remove oxides and especially MgO (spinels) which are a known problem in pistons
2. reduce all alkali elements like Na & Ca below 5 ppm

COVERAL MTS 1565 has been proven to effectively remove oxides and particularly MgO spinel inclusions in an environmentally acceptable manner.

COVERAL MTS 1591 can effectively remove unwanted alkalis according to the following mechanism: Coveral MTS 1591 + [Na] + [Ca] $\rightarrow$ NaCl + $CaCl_2$ (which will float into the dross)

A market leading automotive piston foundry has asked us to use VMET to investigate their melt quality following a customer complaint linked to MgO inclusions.

Table 7 shows the VMET report and findings before and after metal treatment.

Figure 5. MTS treatment in a piston foundry

This VMET analysis was able to identify the presence of:

- excessive amounts of Na & Ca in the melt before treatment
- many small oxides and inclusions in the melt prior to rotary degassing treatment
- 26 MgO spinel inclusions in the sample, smaller than 15µm
- 3 MgO spinel were found to be larger than 15 µm = a real problem for pistons

VMET also showed that MTS 1500 process together with COVERAL MTS 1565 cleaning flux was able to significantly improve melt quality by removing all oxides and MgO inclusions > 15 µm.

This VMET work led to the sales of several MTS 1500 units in this piston foundry.

Piston Foundry	MTS 1500 Process with COVERAL MTS 1591/1565		
Trial	**500 Kg Crucible**		
Sample location	**Before**	**After**	**Explanation**
Na (ppm)	4	0.1	Excellent Alkali removal
Ca (ppm)	7.9	2.6	Excellent Alkali removal
Density Index (%)	7.5	0.1	Fantastic degassing perfomance
Total Aluminum Oxides	64	200	
0.5 – 15 µm	64	200	Breaking up of clusters - not a concern
Σ all oxides > 15 µm	0	0	No oxides found
Total Other Inclusions	69	74	
0.5 – 15 µm	66	74	Breaking up of clusters - not a concern
Σ all inclusions > 15 µm	3	0	Reduction of inclusions
Total MgO & Spinels	29	5	
0.5 – 15 µm	26	5	Reduction of spinels
Σ all MgO > 15 µm	3	0	Reduction of spinels

Table 7. VMET report and findings before and after metal treatment

VMET [8] ASSESSMENT OF CHIP MELTING OPERATION FOR FOUNDRY INGOT PRODUCTION

In recent years, many operations have looked at remelting machining chips in order to produce secondary ingots suitable for aluminium casting production. This is particularly true in Asia when very large amounts of A356 chips are coming from LPDC wheel machining.

But many such operations encounter quality issues as they underestimate the level of oxides created during the remelting of such finely divided chips which have large specific surfaces.

Hence extreme oxidation will create millions of very fine oxide films as shown in figure 6 where VMET found extremely high levels of oxide between 0.5 µm – 15 µm.

Such high levels of oxides will create excessive dross during melting but also aggregate to form larger oxide clusters & films which are the cause of reject castings.

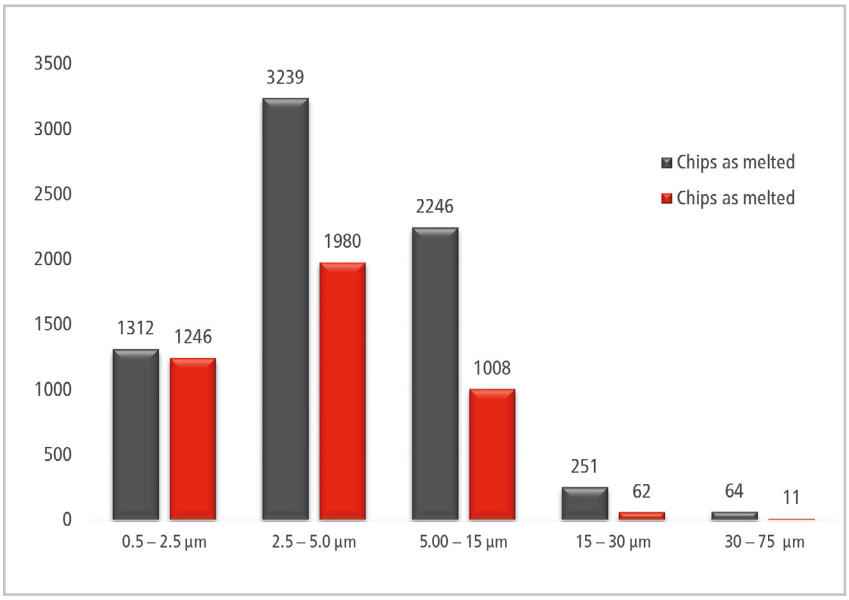


Figure 6. Features in Chip melts by size

Such chip generated melts must undergo intense metal treatment in order to reduce the level of oxides significantly. Strong cleaning fluxes should be applied to de-wet the oxide films and make sure they can be floated into the dross.

One secondary ingot maker asked us to implement such a metal treatment and use VMET to quantify the level of oxides and the improvement observed.

Figure 7 shows MTS 1500 on the fuel fired crucible furnaces that are used to remelt the 100% charges of A356 chips. The melting temperature exceeds 780°C. Foseco implemented a specially designed MTS 1500 type Mark 10 able to treat such chip melting furnaces.

VMET Samples were taken from one chip melting furnace before and after a 10 min MTS 1500 treatment. The SEM pictures with 100x magnification are shown in figure 8 below.

We can see the melt "as melted" shows many defects which are a mixtures of porosity and oxide films. Whereas after the 10 min MTS 1500 treatment, the sample is clean without any visible traces of oxides. This is a visual confirmation that MTS 1500 process is able to achieve good melt quality even with 100% pure melted chips.

Figure 7. MTS 1500 on the fuel fired crucible furnaces used to remelt the 100% charges of A356 chips

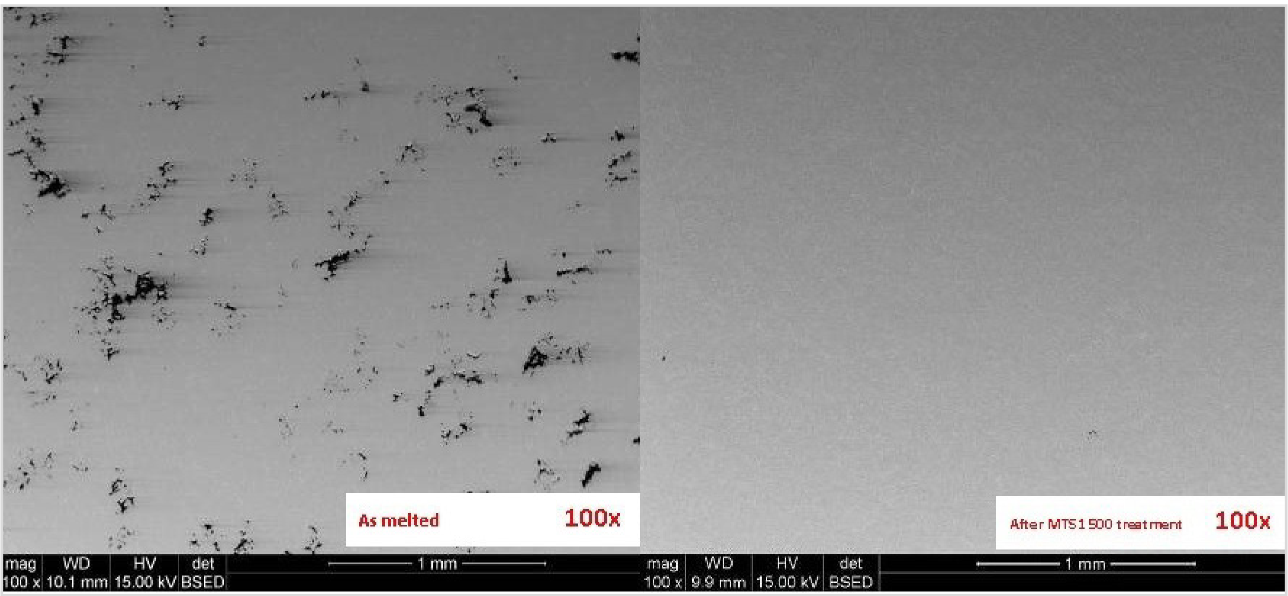


Figure 8. SEM pictures with 100x magnification

Two furnaces 1 & 2 (Table 8) with similar capacity were loaded with the same amount of chips. After a melting time of around 1 hour, the MTS 1500 unit was applied respectively to furnace 1 for 15 min and furnace 2 for 10 min.

All other working parameters were kept identical including:

- Furnace capacity: 750 Kg chips
- Gas flow: 20 l/min
- Flux addition: 1.2 kg (0.16%)
- Rotor Size: XSR Φ 220 mm
- Shaft length: 900 mm
- Treatment temperature: 720°C

The VMET data in table 8, clearly shows that the MTS 1500 treatment was able to significantly reduce most defects especially:

- Total # of features were reduced by 99% after a 10 min MTS 1500 treatment (4307 to 53)
- Total # of pores were reduced by 99% after a 10 min MTS 1500 treatment (3791 to 29)
- Total # of oxides were reduced by 94% after a 10 min MTS 1500 treatment (329 to 19)
- Total # of inclusions were reduced by 97% after a 10 min MTS 1500 treatment (187 to 5)

From this chip melting study, we can conclude that the MTS 1500 process is able to remove more than 98% of all defects in Aluminium melts treated in such crucibles.

Chip Melting	**Furnace 1**		**Furnace 2**	
Sample location	Chips as melted	After 15 min MTS	Chips as melted	After 10 min MTS
Total Features	7116	73	4307	53
Total Pores	3804	63	3791	29
Aluminium Oxides	2958	3	329	19
Other Inclusions	354	7	187	5
0.5 - 2.5 µm	1312	9	1246	17
2.5 - 5.0 µm	3239	21	1980	18
5.00 - 15 µm	2216	21	1008	11
15 - 30 µm	251	19	62	3
30 - 75 µm	64	2	11	4
> 75 µm	4	1	0	0

Table 8. VMET results before and after MTS when melting chips

CONCLUSIONS

Metal treatment is one of the critical parts of the foundry process, which often has a significant impact on casting quality, reject rates and costs. Existing practice may have limitations in terms of quality, efficiency or automation.

The MTS 1500 process clearly demonstrated higher degassing performance and better grain refining efficiency in low-pressure die casting wheels.

In high pressure die casting, MTS 1500 showed significant cost savings in terms of reduced dross generation.

MTS 1500 combined with VMET (Melt Quality Assessment) has clearly proven that it can significantly improve melt quality of Aluminium pistons, wheels, and chip melting, by significantly reducing detrimental oxides and inclusions.

REFERENCES

1. J. Campbell. Castings. Butterworth Heinemann, 2003.
2. Geoffrey K. Sigworth, Understanding Quality in Aluminum Castings.
3. J.G. Kaufman and E.L. Rooy, "Aluminum Alloy Castings", AFS (2005).
4. Philippe Kientzler, Jun Pascual, "MTS 1500 - A robust (blockage-free), reliable, environmentally friendly, lower cost Metal Treatment Station for Aluminium Foundries", 11th Asian Foundry Congress, Guangzhou, November 12th -15th 2011.
5. J.E. Gruzleski, "Treatment of Al-Si Alloys", AFS (1990).
6. M. Timpel et al., Acta Mat., vol.60, p3920 (2012).
7. J. Stonesifer, B. Began, Degassing and Flux Grain Refining in a Continuous Well at Littlestown Foundry, 2019 AFS Proceedings of the 123rd Metalcasting Congress, Atlanta, Georgia, USA, Paper 19-015.
8. Wenwu Shi, Vmet Analysis of Cast Aluminum Alloys, Fundamental, Application, and Statistic Analysis, AFS Conference on high integrity aluminum castings, October 5-7, 2015 Nashville, TN

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